

The Population Consequences of Disturbance Model Application to North Atlantic Right Whales (*Eubalaena glacialis*)

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LONG-TERM GOALS

The Population Consequences of Acoustic Disruption (PCAD) model (NRC 2005) provided a framework to trace the effects of acoustic disturbance through the life history of a marine mammal to its population status. Developments in the model have been designed to determine if the effects of *any* disturbance can be traced from individuals to the population by way of changes in either behavior or physiology, and the revised approach is called PCOD (Population Consequences Of Disturbance). In North Atlantic right whales (*Eubalaena glacialis*), extensive data on health and body condition, anthropogenic impacts, and individual life history exists. The primary goal of this study is to model visual observations of health, human impacts (including entanglements and ship strikes), and whale locations to provide estimates of true underlying condition and individual level survival for right whales. Secondary goals include modeling fecundity, and exploring the feasibility of incorporating acoustic disturbance and prey variability into the PCOD model.

OBJECTIVES

The objectives for this study are to: 1) develop a Hierarchical Bayesian Model to assess right whale biology, 2) assess the relationship between health indicators and reproduction and mortality in right whales, and 3) assess the effects of fishing gear entanglements and sub-lethal vessel strikes on reproduction and mortality in right whales. The objective for FY 2015 was to incorporate the model outputs on health and entanglements into publications for submission by year-end.

APPROACH

The modeling approach was to link visual observations of health, human impacts, and whale locations to estimates of true underlying health and individual level survival (see Thomas et al. abstract). Visual observations of health included: body condition, skin condition, presence of cyamids on the blowholes, and the presence of rake marks (Pettis et al. 2004). The true health status integrates many of the natural and anthropogenic disturbances that alter the observable health of a whale. The natural disturbances or stressors include the calving cycle of mature females, and the age-related health of the whale. From these estimates we can then assess how anthropogenic disturbances like entanglement with fishing gear affect the underlying health of individuals. We fit the model to data to infer the parameters governing the biological processes of health, reproduction, movement, and survival, and to provide estimates of the links between observation and process for both health and human impacts. In order to ensure the results reflected biological reality, we modified several components of the model by testing its output against animals with detailed known histories, and by convening meetings between the modelers and the biologists most familiar with the species. Finally, we participated in an ONR workshop to determine the applicability of the model to assessing the effects of acoustics on the population.

We have refined and applied the PCOD model developed for right whales (Schick et al. 2013). The model links photographic evidence of health from every photographed sighting to the first process model, which provides inference on how health changes over time. Every photographed sighting of a right whale also contains location information, which has been used in the second process model to estimate location and transition probabilities between locations. Finally, estimates of the current states (health and location) inform individual survival. We have met regularly to review statistical output from multiple runs of the model, either in Boston or by internet (Skype, Teamviewer) These discussions have led to model changes, which have been implemented to produce the final datasets and model outputs. One manuscript on health and reproduction has been submitted to MEPS, and is currently under revision based on reviewers comments. The second manuscript, on the effects of entanglement on right whales health, will be submitted by year-end. Both papers include modeled health trajectories over time in different population sub-categories.

WORK COMPLETED

Manuscripts

We have published the following manuscripts pertaining to the PCOD Modeling:

- a. Schick, R. S., Rolland, R., Kraus, S., Pettis, H., Knowlton, A., Hamilton, P., Kenney, R., and J. Clark. 2013. Using Hierarchical Bayes to understand movement, health, and survival in critically endangered marine mammals. *PLoS ONE* 8(6): e64166. doi:10.1371/journal.pone.0064166.
- b. Schick, R. S., Rolland, R., Kraus, S., Pettis, H., Knowlton, A., Hamilton, P., Thomas, L., Harwood, J., and J. Clark. 2014. Effects of Model Formulation on Estimates of Health in Individual Right Whales (*Eubalaena glacialis*). *Effects of Noise on Aquatic Life II*. Springer Press
- c. Fleishman, E., Burgman, M., Runge, M., Schick, R. S., and S. Kraus. 2014. Expert elicitation of population level effects of disturbance. *Effects of Noise on Aquatic Life II*. Springer Press

- d. Rolland R.M., R. S. Schick, H. M. Pettis, A. R. Knowlton, P. K. Hamilton, J. S. Clark and S. D. Kraus. In revision. Health of North Atlantic right whales (*Eubalaena glacialis*) over three decades: from individual health to demographic and population trends. *Marine Ecology Progress Series*.
- e. Knowlton, P. K. Hamilton, H.M. Pettis, S. D. Kraus, R.M.Rolland, and R. S. Schick. Measuring the effects of entanglement on North Atlantic right whale health and survival using hierarchical bayes. Will be submitted by December 31st for publication.

Travel

- f. Kraus presented at the Annual ONR Program Review May in 2014
- g. Schick travelled to Boston meetings with the New England Aquarium researchers
- h. Kraus and Rolland - June 2014 Workshop on the feasibility of incorporating acoustic and hormone data into model (organized by E. Fleishman)
- i. Kraus, Rolland, Knowlton, and Pettis travelled to the N. Atl. Right Whale Consortium in New Bedford, MA, November 2014 and 2015

Presentations

- j. Kraus et al December 2013 Biennial Marine Mammals Conference, Dunedin, NZ (*Talk*)
- k. Kraus et al May 2014 Office of Naval Research Program Review, Arlington, VA (talk)
- l. Kraus et al. November 2014 North Atlantic Right Whale Consortium, New Bedford, MA (talk)
- m. Knowlton et al. presentation at the San Francisco Mammal Conference in December 2015 (talk)
- n. Rolland et al. presentation at the San Francisco Mammal Conference in December 2015 (talk)

RESULTS

Every right whale has a modeled health timeline graph that incorporates the photographic data stream on the four health parameters, and depicts all entanglement events, and calving events (Figure 1). Individual health profile data for adult males and older juveniles (3-8 yrs) were compiled to create estimates of health for the entire population (Figure 2). Because there are periods of naturally poorer body condition for certain sub-categories, e.g. lactating females and recently weaned juveniles, we examined health estimates for different sub-population categories separately (data not shown), and did not include these groups in the overall population health estimates.

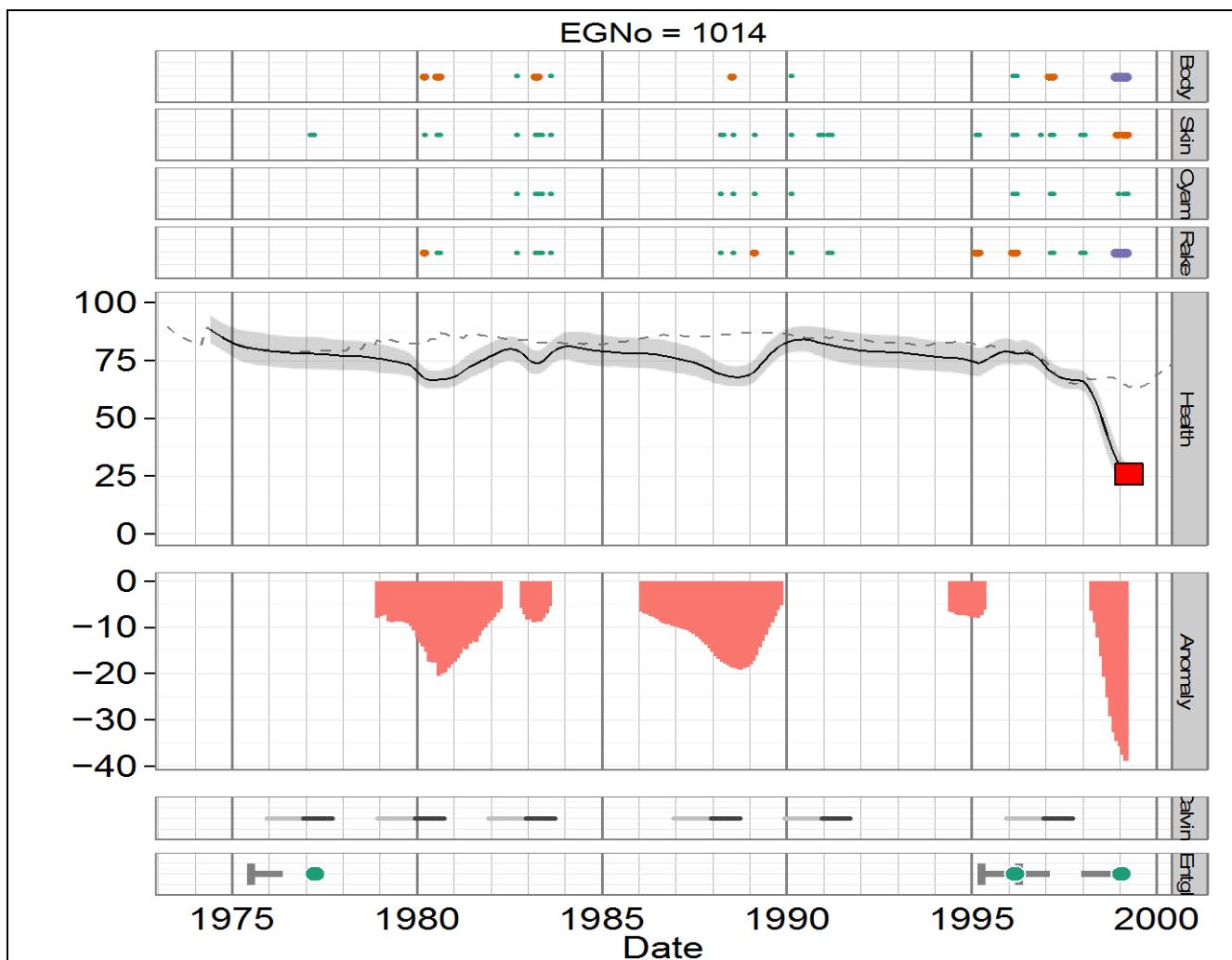


Figure 1. Modeled health estimates (middle panel labeled “Health”) for right whale #1014, with 95% CI (gray area). Dashed line represents population health. “Anomaly” panel depicts negative deviations of individual health from population health. Data observations are shown (top panels) for body fat, skin condition, presence of cyamids, and the presence of rake marks (green = good; orange = medium; purple = poor). Gestational status (grey = pregnancy year; black = calving year), and entanglement (green = minor, orange = moderate, purple = severe injuries; grey line: before symbol = timeframe within which entanglement event occurred, after symbol = duration of time carrying gear for those cases where gear was attached) are not included in the model, but are shown in bottom panels. This animal died in 1999 following a ship strike.

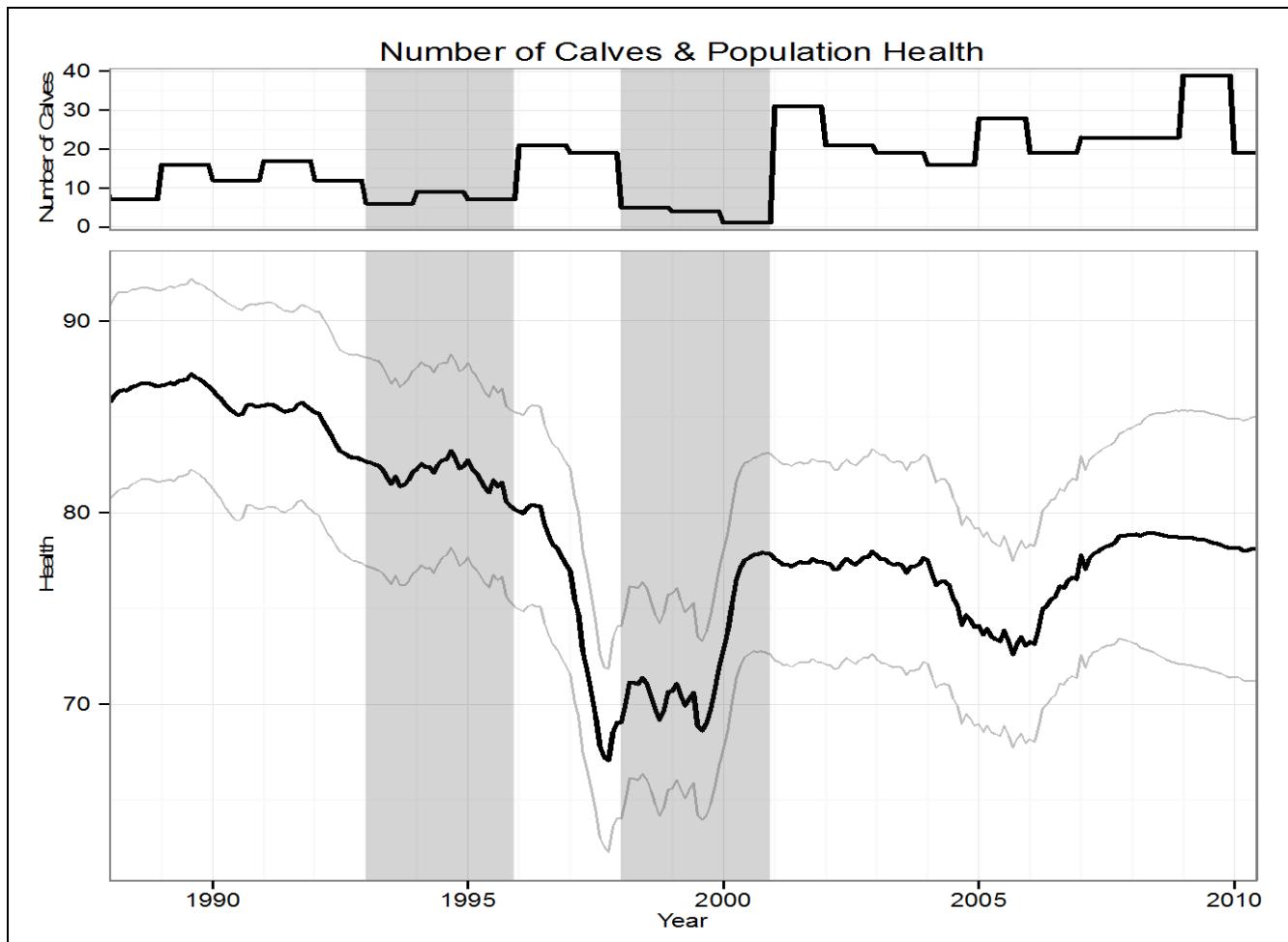


Figure 2. Number of calves born into the population each year (top panel) with estimates of population level health over 25 years (bottom panel). Shaded rectangles indicate periods of reduced calving rates. Note the y-axis scale is truncated to highlight the pattern. Known periods of low vital rates in the late 1990's are reflected in the low mean health, with the larger decrease in fecundity corresponding to the lower average population health.

A major goal of this effort has been to look at the relationship between animal health and population effects. The first work on this was to assess the health of adult females which were available to become pregnant in a given year. Right whales generally have 3 year calving intervals; year one is lactation, year 2 is a resting year, and year three is a pregnancy year. Females are considered “available” to be pregnant in all years following the resting year until the next gestational year. We used the model output to test whether there was a difference in health between those available females who transitioned to pregnant in a given year vs. those that did not become pregnant. The results showed that females that got pregnant had a mean health score of 74.55 and those that did not produce a calf had a mean score of 72.96, and this difference was significant ($t = 4.787$, $p = 1.751e-06$) (Figure 3), suggesting that relatively small changes in female right whale health may influence reproductive success.

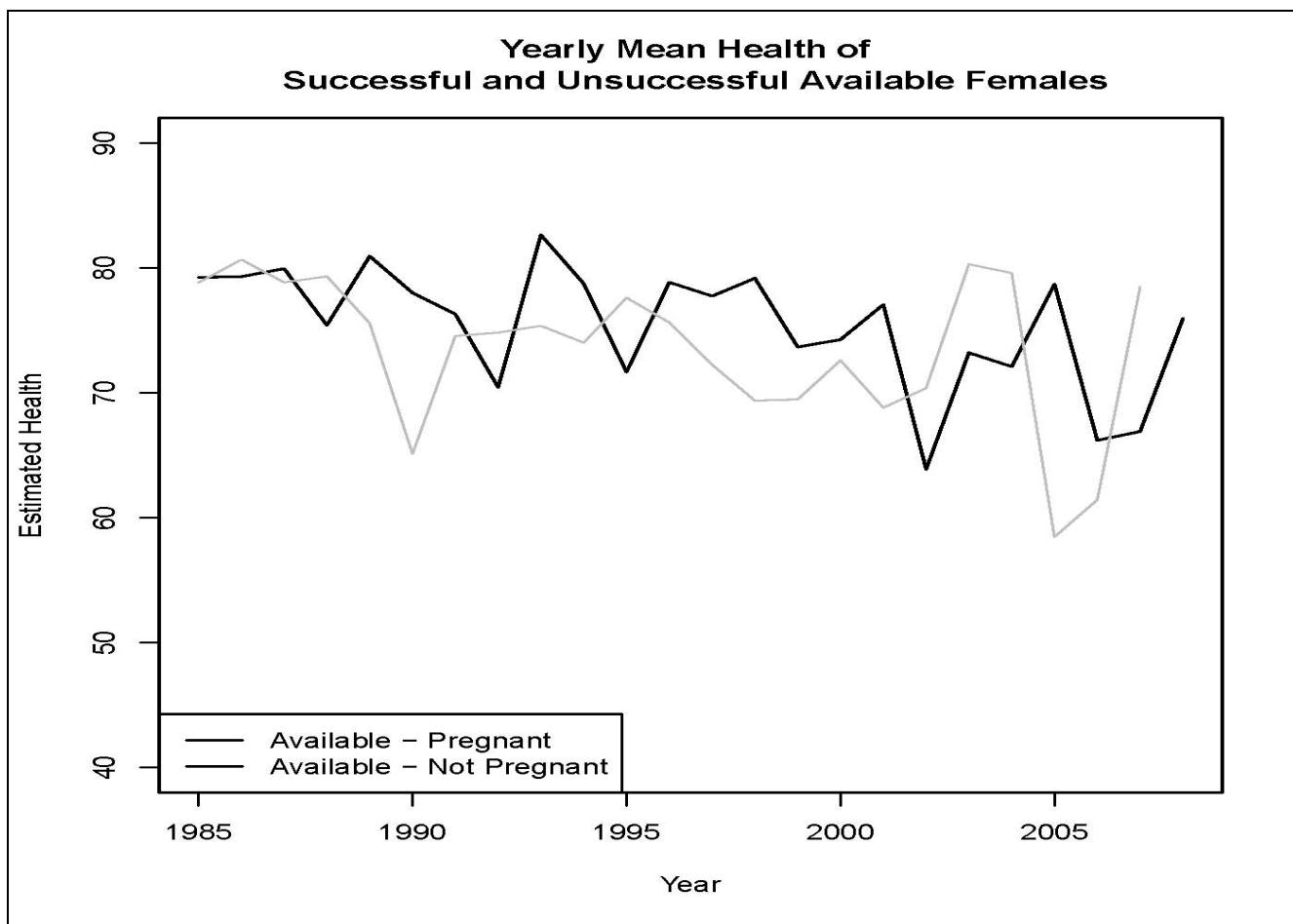


Figure 3. Summarized health scores by year of available females which became pregnant (dark line) and available females which did not become pregnant (grey line).

The next steps have been to look at entanglements of right whales as a proxy for a disturbance. Over 82% of North Atlantic right whales have been entangled in fishing gear at some time, and such entanglements occur between 30 and 60 times per year in the extant population (Knowlton et al. 2012). Six entanglement categories were developed – minor, moderate, or severe injuries, with or without attached gear, and applied to each of 1,032 entanglement events documented from 1980-2009.

In whales that still had rope attached after an entanglement interaction, the observed duration of the animal carrying gear ranged from less than a day to many years. Here we examined the consequences of various entanglement injury severity and duration levels on right whale health both before and after the period within which the entanglement occurred, and 12 months after an entanglement was known to have ended. Monthly median health scores ranging from 0-100 were calculated for each individual whale's entanglement timeframe and were summarized by category. Using GLMs, these scores were compared to un-impacted whales, i.e., all whales' health scores that were not within an entanglement timeframe.

The six categories were compared for two demographic groupings: 1) non reproductive whales including adult males, juveniles, and females up until their first calving; 2) reproductive females from first-calving onward.

For the non-reproductive group, entanglements reduced health for severe cases with and without gear (health scores of 52 and 58, respectively), compared to un-impacted whales (77), although other comparisons within that group were not significant. For reproductive females, all injury categories showed significantly reduced health (54 to 71) when compared to un-impacted females (76). Survival of whales decreased as injury severity increased, with “severe with gear” cases significantly worse than “minor” cases.

For all whales, the results show that most whales decline in health as a result of entanglement, but that severe entanglements lead to significant declines in mean health scores (Figure 4). In addition, whale health recovery after entanglement events is not certain. Severely entangled whales, whether they had originally been observed carrying gear or not, continue to experience large declines in health for 12 months after their first “gear free” sighting (Figure 5).

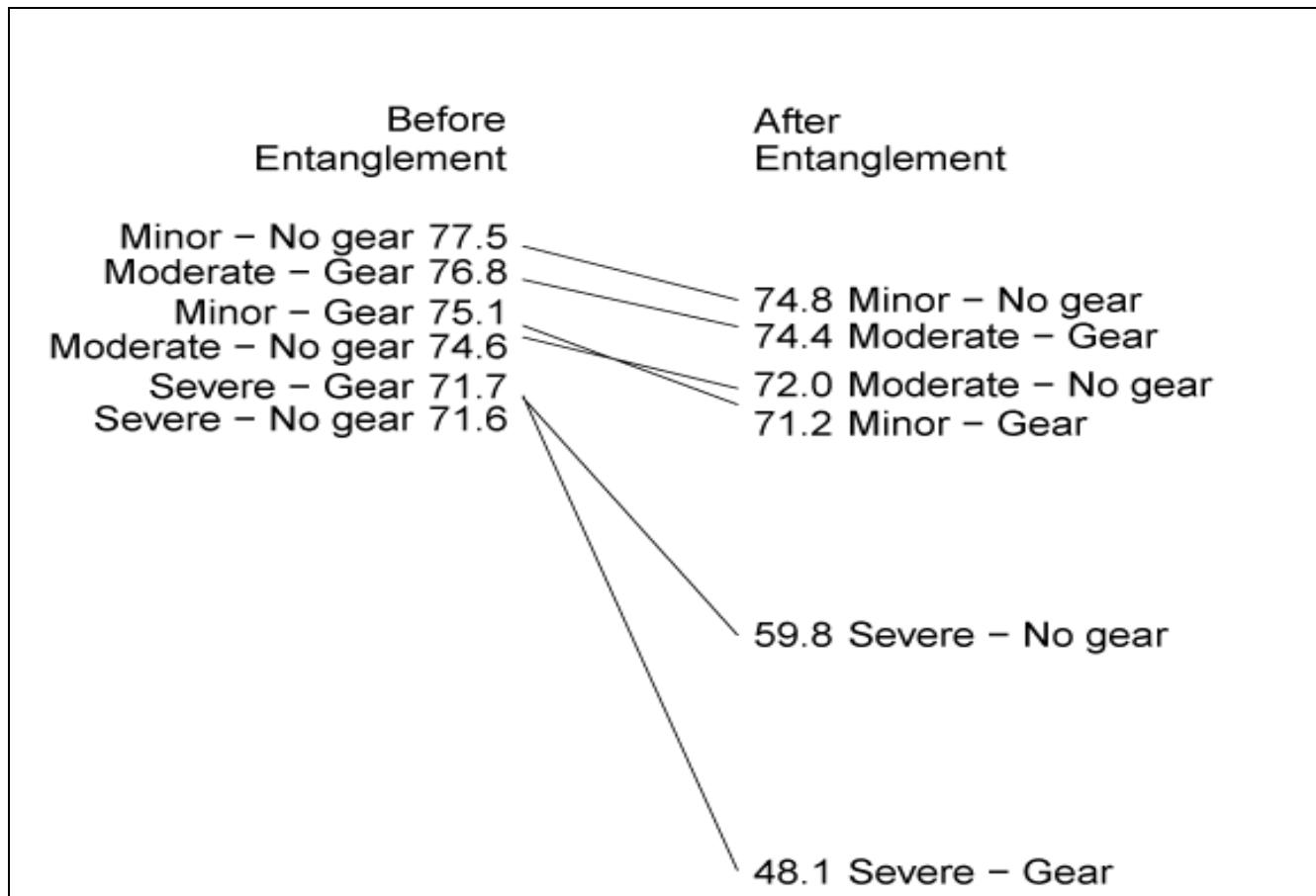


Figure 4. Mean health scores for whales before (left side) and after (right side) an entanglement event. All categories of entanglement (minor, moderate, and severe) are also classified by whether they were carrying gear.

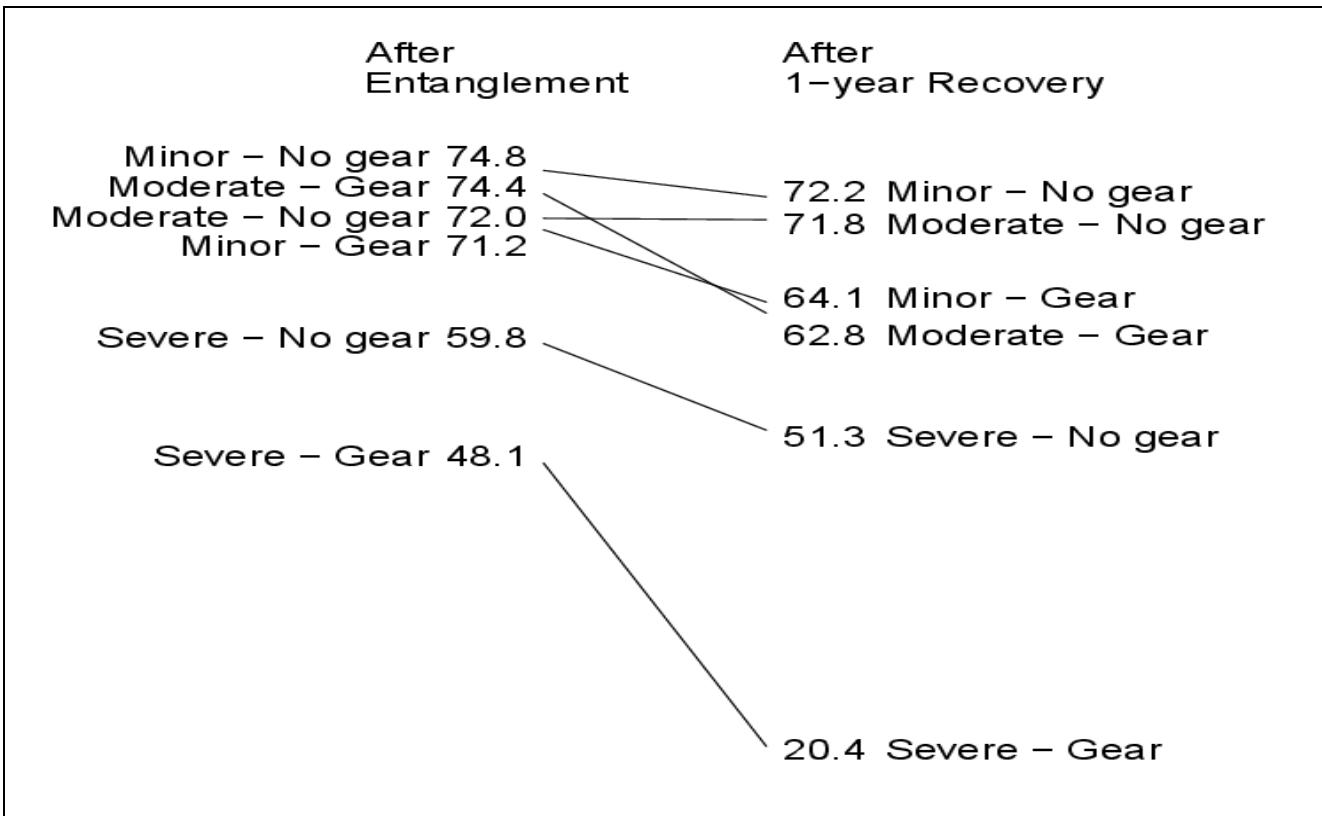


Figure 5. Mean health scores for whales at the first sighting after an entanglement (left side), and at 12 months later (right side). All categories of entanglement (minor, moderate, and severe) are classified by whether they were carrying gear.

Additional analyses to refine estimates of mortality based on entanglement severity confirm the other analyses, and suggest that entanglement severity is the dominant factor in determining survival of entangled whales (Figure 6).

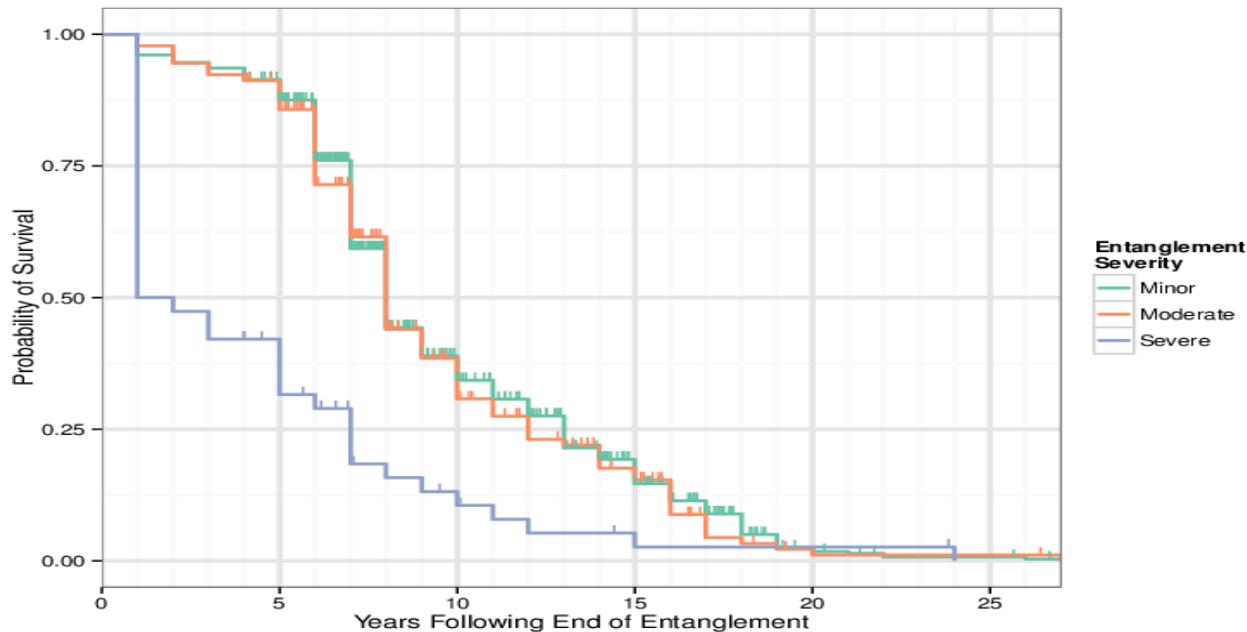


Figure 6. Probability of survival following entanglement by severity.

Discussions are also underway about modeling approaches that might incorporate other types of disturbance events, including both non-lethal ship strikes, acoustic disturbance, and prey reductions.

The magnitude of the health declines shown in the entanglement analyses for whales carrying gear and with severe entanglements (Figures 4 and 5) exceeds the magnitude of differences shown between available females which got pregnant and those that did not (Figure 3). In the case of entanglements, which are widespread through the North Atlantic right whale population, the integration of these model results will allow estimates of population level effects from this type of disturbance.

Planned activities

- Oral presentations at the Society for Marine Mammalogy conference in December
- Publication of both manuscripts on health and entanglements

IMPACT/APPLICATIONS

Despite continuous protection, studies, and monitoring, North Atlantic right whales have been critically endangered for decades (Kraus et al. 2005). Previous population forecasts have been ominous (Caswell et al. 1999, Fujiwara & Caswell, 2001), and several dips in vital rates of the population have been documented in the past 20 years (Kraus & Rolland, 2007). This modeling approach may help identify those anthropogenic or natural stressors which most affect mortality and/or reproduction, and can fill a critical need as different management scenarios and/or interventions are considered.

Aggregated individual health estimates can be used together with the sub-population health summaries to more completely understand past population trajectories, the relationship between adult female

health and reproductive success, and to estimate how future changes in health may reflect particular disturbances. This work lays the foundation for the potential use of the individual health estimates together with information on entanglements, vessel strikes, noise, and other stressors, to examine of the population consequences of these types of disturbance.

While these model analyses are focussed on right whales, photographic observations of condition have been used to evaluate health in other cetaceans (see, for example, Bradford et al. 2012). It is feasible to extend this model to other well studied species, where photographic data may provide indicators of underlying health. By using photographic observations with this modeling approach, we can evaluate how the condition of whales varies over time and space, and in response to specific extrinsic factors. This will provide critical insights into risk factors for both individual whales and their populations.

RELATED PROJECTS

The New England Aquarium's Ocean Health and Marine Stress Program includes studies of stress in beaked and sperm whales (R. Rolland, PI; ONR # N000141110540), and a study on the detection and use of hormones from right whale respiratory exudate (K. Hunt, PI; ONR # N000141310639). As part of the New England Aquarium's Marine Health Program, we are involved in the broader PCOD modeling studies (Len Thomas, PI, ONR Contract # N000141210286, and Erica Fleishman, PI, ONR contract # N000141210274).

PUBLICATIONS

- Fleishman, E., M. Burgman, M. C. Runge, R. S. Schick, and S. D. Kraus. 2014. Expert elicitation of population-level effects of disturbance. *in* A. N. Popper and A. Hawkins, editors. Effects of Noise on Aquatic Life II. Springer. [2014]
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